OECD/NEA KRITZ-2 UO_2 AND MOX BENCHMARKS

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ABSTRACT

The international Expert Group on Reactor-Based Plutonium Disposition (TFRPD) has been established at the OECD/NEA to facilitate the sharing of existing information and experience in the physics and fuel behavior of MOX fuel as it relates to the disposition of weapons-grade plutonium. One of the many recent activities of this Experts Group is the analysis of several critical configurations of the KRITZ reactor. In total, three core configurations were considered, two with UO_2 fuel and one with MOX fuel. Measurements were performed for room temperature as well as elevated temperatures (~245°C). Solutions were obtained from several participants using both deterministic and Monte Carlo methods. The calculational results generally show a slight negative bias in k_{eff} of about 0.2 – 0.6% for the UO_2 configurations and about 0.1% for the MOX core. The relative fission rate results generally lie within a band of ±2% for all cases with maximum errors approaching 4 – 6%.

1. INTRODUCTION

Two of the nuclear weapons countries (Russian Federation and the USA) have declared part of their weapons-grade plutonium stockpiles surplus to their national defense needs. This material must be disposed of, and one of the recommended means is burning the material as fuel in existing reactors thereby transforming it into spent fuel. In fact, reactor-based disposition is the primary alternative since the immobilization was removed in 2001 as a disposition option in the USA. However, the experience in these two countries with mixed oxide fuel (MOX) is relatively small compared with that accumulated in European countries and Japan. An international Experts Group has been established at the OECD/NEA to facilitate the sharing of existing information and experience in the physics and fuel behavior of MOX fuel as it relates to the disposition of weapons-grade plutonium.

More specifically, the Expert Group on Reactor-Based Plutonium Disposition (TFRPD) deals with the status and trends of reactor physics, fuel performance and fuel cycle issues related to the disposition of weapons-grade plutonium as mixed oxide fuel. Its objectives are to provide up-to-date information and develop a consensus regarding core and fuel cycle issues with weapons-grade plutonium disposition in thermal water reactors (PWRs, BWRs, VVER-1000s, and CANDUs) and fast reactors (BN-600). The topics covered include core physics, fuel performance and reliability, thermal water reactor and fast reactor fuel designs, fuel management approaches for maximizing weapons-grade plutonium disposition rates, and fuel cycle flexibility. The TFRPD also aims to provide advice to the nuclear community on the scientific and technical developments needed to meet requirements (e.g. data, methods, and validation experiments) for implementing weapons-grade plutonium disposition approaches. In this regard, activities are closely coordinated with other NEA groups such as the Working Party on Physics of Plutonium Fuels and Innovative Fuel Cycles (WPPR). A summary of recent activities of the Expert Group was recently presented at an International Meeting [1].

As a part of the work program of the Expert Group, the OECD/NEA has been able to obtain experimental data for benchmarking activities and further distribution to those who may have an interest. Under these efforts a series of experimental measurements in the KRITZ reactor at Studsvik has been released. These experiments, discussed in more detail in Section 2, were performed with UO_2 and MOX fuel at temperatures up to 245°C with criticality conditions and fission rate distributions being measured. Based on these experiments, specifications were created and a benchmarking activity was included in the Experts Group work program. Several organizations performed the analysis of these experiments and the results have been tabulated and compared. It should be noted that these experiments have been widely used for data validation (see Ref. 3, for example); however, only the results obtained as a part of the benchmarking activity of the Experts Group will be reported.

2. EXPERIMENTAL BENCHMARK DESCRIPTION

2.1 EXPERIMENTAL FACILITY DESCRIPTION

The KRITZ reactor operated at Studsvik, Sweden, during the first half of the nineteen-seventies. The vertical and horizontal cross sections of the KRITZ reactor are shown schematically in Fig. 1 The KRITZ reactor consisted of ~5 m high cylindrical pressure tank with ~1.5 m diameter. The tank contained the insert vessel. The outer part of the insert vessel was cylindrical with only slightly smaller diameter than the pressure tank. The fuel rods were placed inside the inner part of the insert vessel, which had a square cross section with side length of ~1 m. The square-shaped part was filled with water up to the level required to obtain criticality. Typical water level at criticality was below the top of the fuel, so top portions of the fuel rods extended in the steam region. The thin annulus between the pressure tank and the insert vessel outer part was filled with water up to the same level as the square-shaped part and was connected to the probe outside the pressure tank where the water level was measured (See Fig. 1). The space between the outer and the inner part of the insert vessel (i.e., outside the square-shaped region) was a dump region. The dump region was empty during normal reactor operation; more precisely, it was filled with saturated steam. The safety shutters, neutron detectors, and neutron source were also located in this area. In the case of a scram signal the safety shutters would open quickly and water would flow into the dump region, which would result in lower water level around the fuel and therefore lower reactivity.

2.2 EXPERIMENT DESCRIPTIONS

The "KRITZ experiments" included a series of criticality experiments on light water moderated lattices with uranium rods, mixed-oxide rods or both, at room temperature and at temperatures up to ~245°C. Criticality was attained by controlling the boron content in the water and by adjusting the

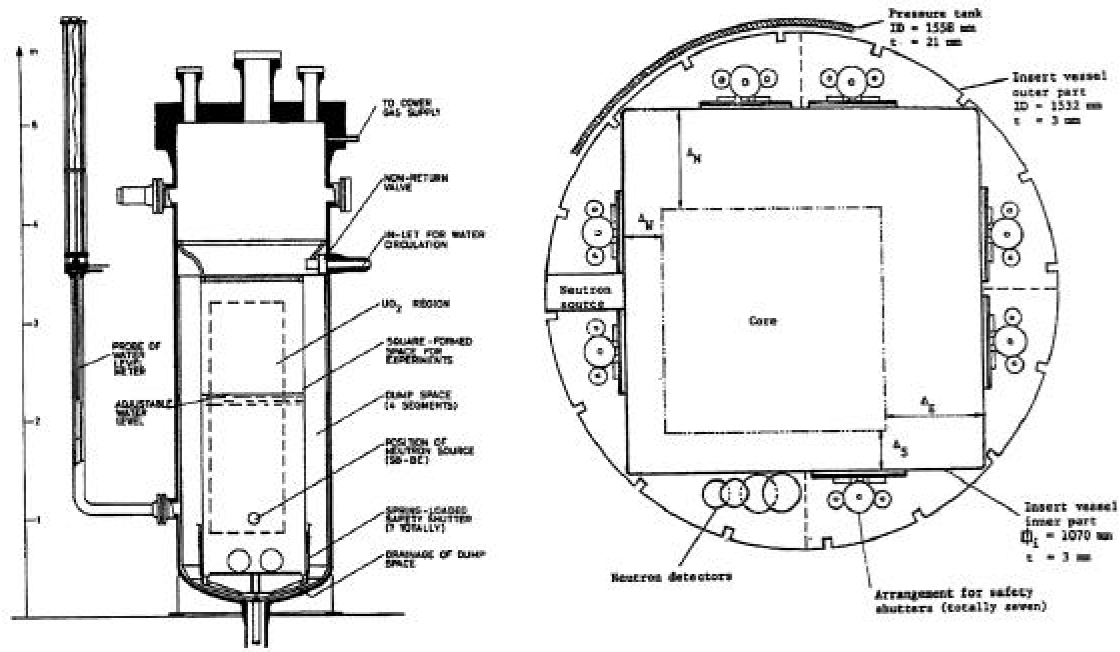

Figure 1. Vertical and horizontal section of the KRITZ critical facility.

water level. Critical levels were measured at low power, often as low as 10 W, to minimize the activation of the fuel. Measurements of the activated copper wires and gamma scans of the fuel rods were used to determine experimentally the axial buckling. For most of the cores measured relative powers for selected rods, obtained from gamma scans, are provided. The data released describe three experiments: two with uranium rods (KRITZ-2:1 and KRITZ-2:13) and one with mixed-oxide rods (KRITZ-2:19) [2]. The critical configurations of each core are given in Table I.

Table I. Specification of Critical Configurations

Core	Fuel	Rod Pitch (mm)	No. of Rods	Temp. (°C)	Boron Conc. (ppm)	Water Height (mm)
KRITZ-2:1	UO_2, 1.86 wt. % ^{235}U	18.0	44×44	19.7	217.9	652.8
				248.5	26.2	1055.
KRITZ-2:13	UO_2, 1.86 wt. % ^{235}U	14.85	40×40	22.1	451.9	961.7
				243.0	280.1	1109
KRITZ-2:19	MOX, 1.5 wt. % PuO_2, 91.41 at.% ^{239}Pu	16.35	25×24	21.1	4.8	665.6
				235.9	5.2	1042

2.3 BENCHMARK SPECIFICATIONS

Based on the original experiment descriptions given in Ref. 2, a set of benchmark specifications for the three core configurations shown in Table I was created and distributed. These benchmark specifications were developed to provide a concise description of the configurations that can be used by two-dimensional lattice-physics codes as well as by three-dimensional neutron transport and Monte Carlo codes. The models provided in the benchmarks closely match the experimental setup. Therefore, it is considered that the models have the same k_{eff} as the experiments. Further sensitivity studies are underway to substantiate this statement. In the course of the benchmarking activity, the specifications for KRITZ-2:19 were further developed to be used in a OECD/NEA pilot project on the preservation of experimental data, known as the International Reactor Physics Benchmark Experiments Project (IRPhEP). In addition to the core configurations, the specifications also requested unit cell calculations of each pin type to provide more detailed information for comparison among the various data libraries and codes that were used in the analyses.

3. CALCULATIONAL RESULTS AND COMPARISONS

A total of six organizations participated in this OECD/NEA benchmarking activity. The participants include:

- Russian Research Center "Kurchatov Institute" (KI), Russia with the MCU Monte Carlo code with DLC/MCUDAT-2.1 data library (based on ENDF/B-VI, JENDL-3.2, and BROND, and MCU group evaluations and compilations),

- Korean Atomic Energy Research Institute (KAERI) using the HELIOS collision probability code with ENDF/B-VI data,

- KAERI and Nuclear Energy Agency (NEA) working jointly using the MCNP-4B Monte Carlo code with ENDF/B-VI data,

- Gesellschaft fuer Anlagen-und Reaktorsicherheit (GRS) mbH, Germany in cooperation with University of Stuttgart, Germany with MCNP-4C with JEF 2.2, JEFF-3T2, and JENDL-3.2 data; THREEDANT discrete ordinates calculations with JEF-2.2 data,

- Oak Ridge National Laboratory (ORNL) using HELIOS with ENDF/B-VI data,

- SCK•CEN, Belgium with MCNP-4C with JEF 2.2 data.

The HELIOS and MCU calculations use the experimental buckling values to perform 2-D calculations, while the MCNP and THREEDANT calculations use a 3-D representation of the geometry.

A summary of the k_{eff} results is presented in Fig. 2 for the three core configurations at the low (~20°C) and high (~245°C) temperatures in terms of the mean and standard deviation of the submitted results. The results generally show a slight negative bias in k_{eff} of about 0.2 – 0.6 % for the LEU cores and about 0.1 % for the MOX core. The results in Fig. 2. also show a nearly constant bias between the hot and cold states for KRITZ 2:13 and 2:19 indicating a good prediction of the temperature reactivity effects. The details of the k_{eff} results submitted for KRITZ-2:19, the MOX configuration, are presented in Fig. 3. As previously mentioned, most of the solutions under-predict the critical k_{eff} value, but the majority of the solutions are within ±0.2% (i.e. 200 pcm). The reported experimental uncertainty for this configuration is 80 pcm [2].

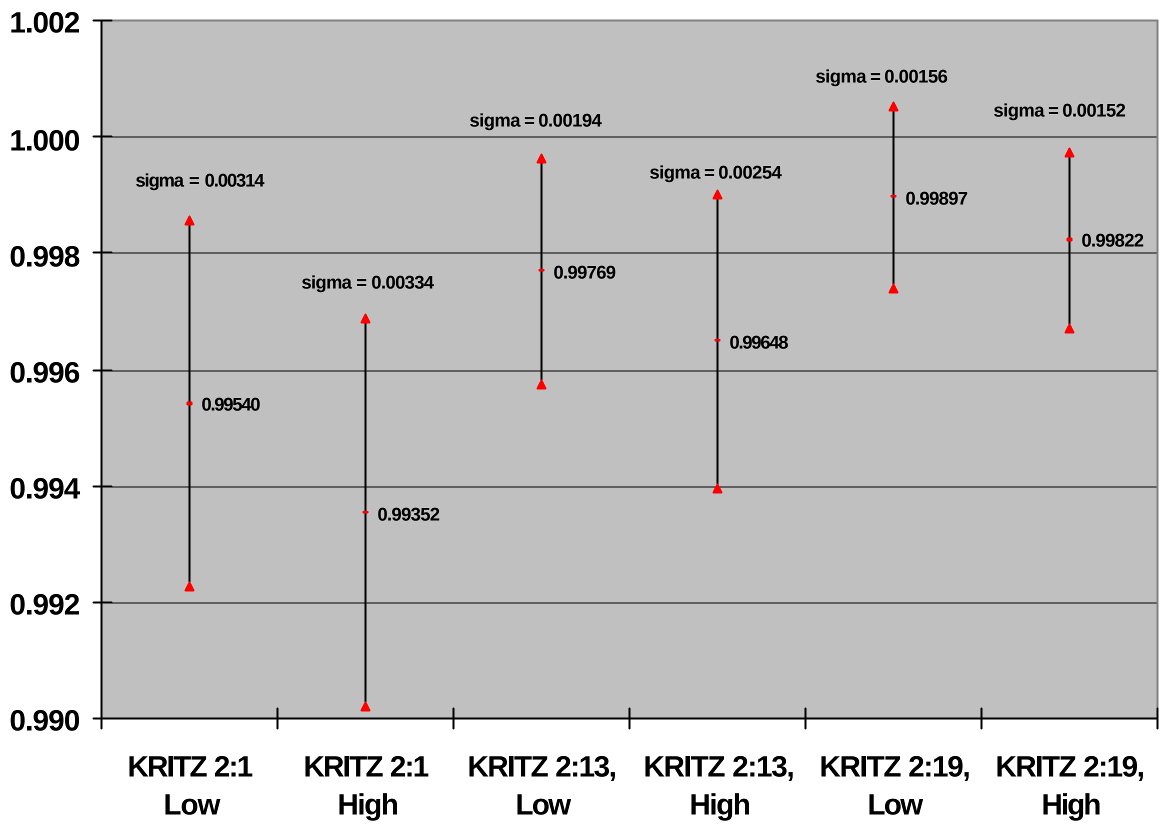

Figure 2. Summary of the KRITZ-2 k_{eff} results.

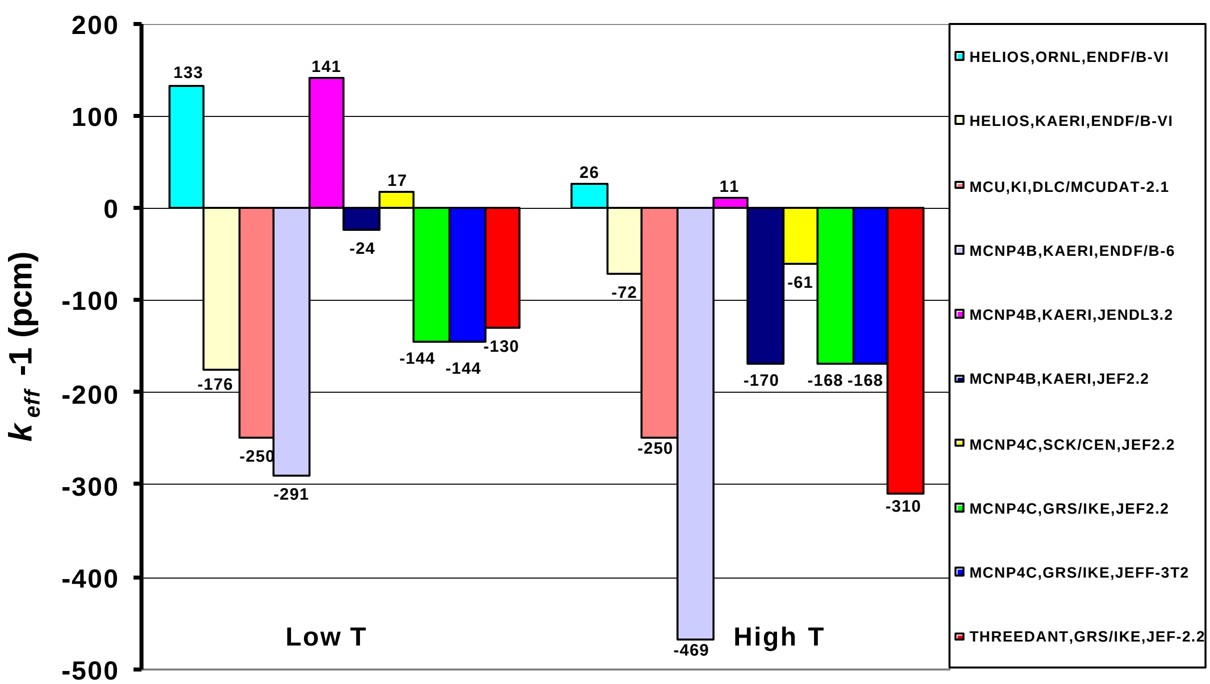

Figure 3. Criticality results for KRITZ-2:19 configuration.

In the initial comparisons, discrepancies between the MCNP solutions were observed and could not be directly explained. Additional calculations performed by GRS in an effort to resolve the discrepancies show a strong dependence on the cross section libraries, primarily the ^{235}U evaluation. These additional calculations were performed with JEF-2.2, JEFF-3T2 and JENDL-3.2 libraries with MCNP-4C. The MCNP k_{eff} results using JEF-2.2 data are significantly low. Calculations performed with JEFF-3T2 (and ENDF/B-VI.5, which utilizes the same ^{235}U data) show even larger discrepancies. The JENDL-3.2-based results show the best agreement. Additional sensitivity studies are planned to further investigate these discrepancies.

In addition to k_{eff}, comparisons of the fission rates for each configuration have also been performed. The relative fission rate results generally lie within a band of ± 2% for all cases with maximum errors approaching 4 – 6%. There is no discernible difference in accuracy between the LEU and MOX fission rate results. The cold and hot pin powers (actually the fission rates) for the KRITZ-2:19 (MOX) configuration are shown in Figs. 4 and 5 for pins forming horizontal and vertical rows through the center of the critical assembly. The reported experimental uncertainties are ~±1% except for a few pin locations that are known to have larger uncertainties due to bent rods or inhomogeneities. Two such rods, known to have larger experimental uncertainties, are rod number 8 in Fig. 4 and rod number 12 in Fig. 5. Note that the MOX core configuration does not involve any UO_2/MOX interfaces that occur in partial MOX core loadings and therefore do not provide a validation of the modeling of these interface effects.

4. SUMMARY AND CONCLUSIONS

In summary, as part of the on-going activities of the OECD/NEA Expert Group on Reactor-Based Plutonium Disposition, several critical experiments performed at the KRITZ facility were calculated with several different library and code combinations. The calculational results generally show a slight negative bias in k_{eff} of 0.2 – 0.6% for the UO_2 configurations and about 0.1% for the MOX core. The relative fission rate results generally lie in a band of ±2% for all cases with maximum errors approaching 4 – 6%. In the course of the study, investigations to resolve discrepancies among several participants using the same code (MCNP) revealed that the results showed a strong dependence upon the cross section library utilized and in particular the ^{235}U evaluation.

ACKNOWLEDGEMENTS

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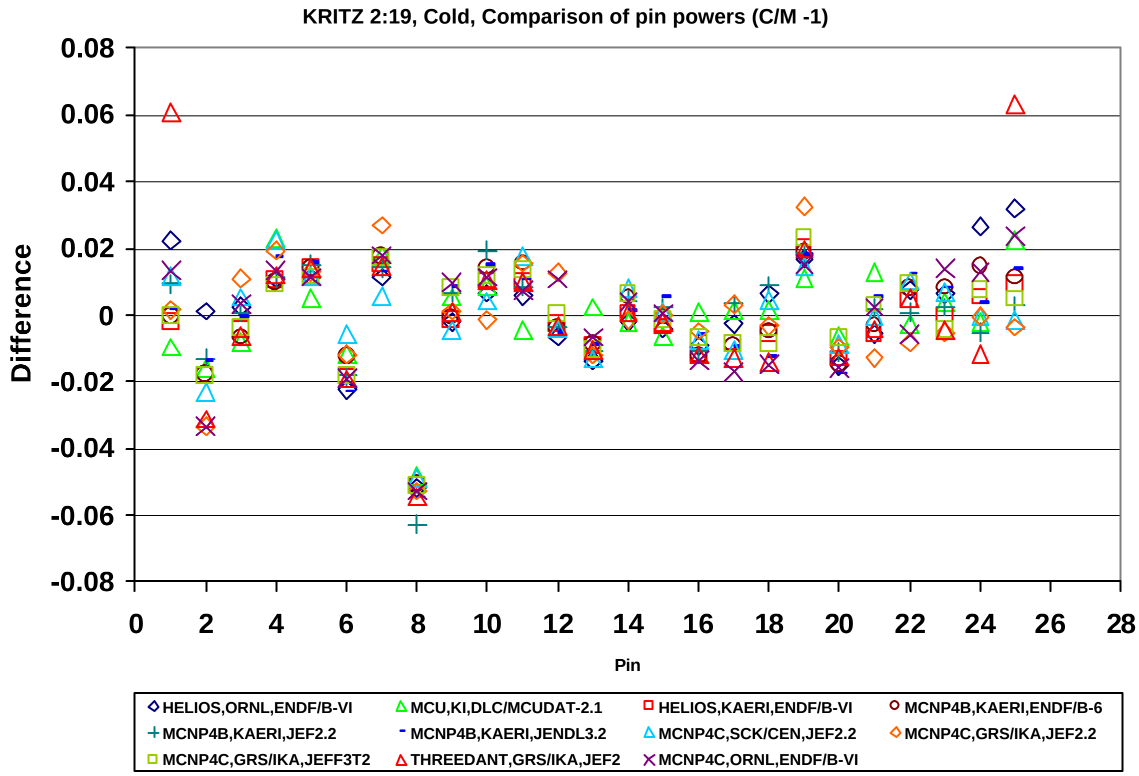

Figure 4. Comparison of the KRITZ-2:19 cold condition pin powers (fission rates) results with the experimental values.

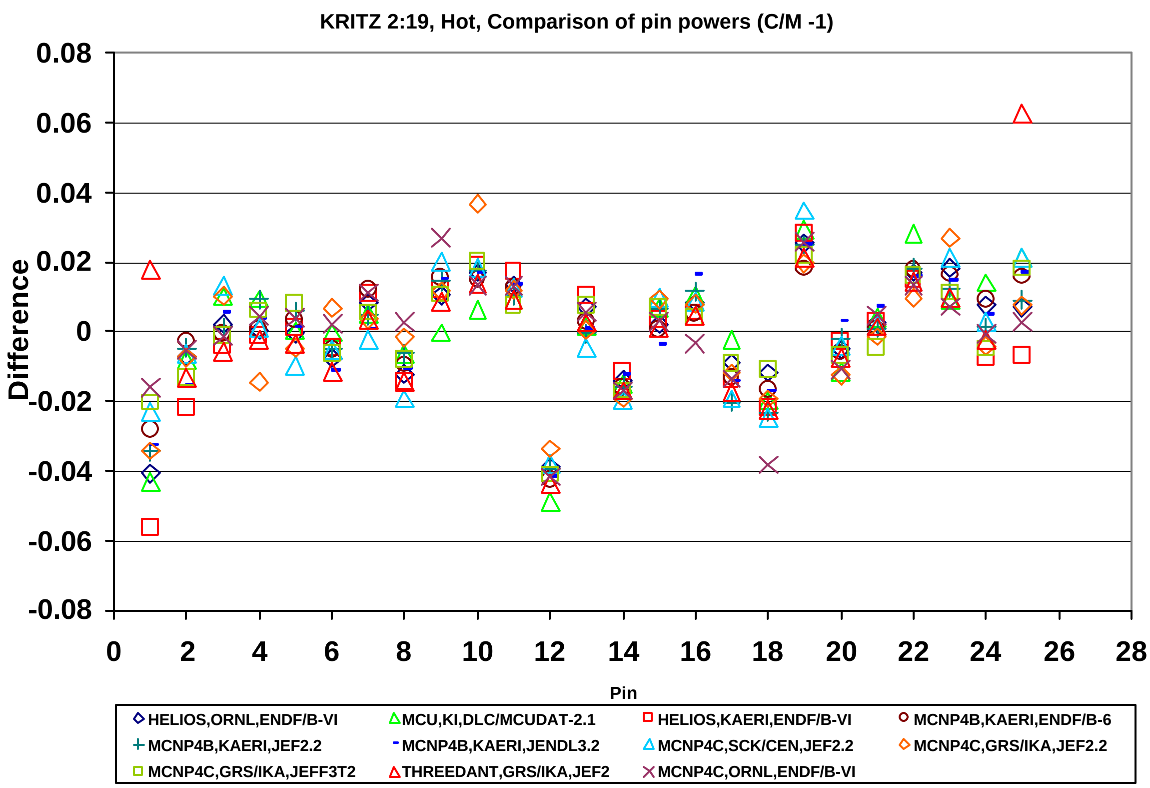

Figure 5. Comparison of the KRITZ-2:19 hot condition pin powers (fission rates) results with the experimental values.